# *Iteration #2 Results*

## *Ecosystem Function – Water Quality Work Group*

## *Total Dissolved Gas Assessment*

SRT Meeting – February 28, 2013
Mike Schneider USACE

# Metrics/Evaluation Criteria

- Spillway releases entrain air bubbles that when exposed to hydrostatic pressures force the absorption of atmospheric gases into solution resulting in the supersaturation of total dissolved gases (TDG)
- Structural and operational attributes of dams have evolved with regards to characteristics of TDG exchange
- Spillway flows reset the TDG supersaturation while powerhouse flows generally retain the forebay TDG levels
- Fish acclimated to supersaturated waters that move into shallower environments may cause TDG to come out of solution forming bubbles in body tissues resulting in gas bubble trauma

# Metrics/Evaluation Criteria

- TDG saturation in the forebay and tailwater of Dams on the Columbia and Snake Rivers, Headwater Projects
  - State water quality standards  TDG 110% saturation
  - Fish passage projects rule adjustment or waiver April-August
    - 115% limit Forebay of Dam (12 hr average)
    - 120% limit in Tailwater of Dam  (12 hr average)
    - 125% limit anywhere (1-2 hr average)
  - TDG Metrics summarize the duration in days of TDG saturation falling above a given threshold  (110-140, in increments of 5 %)

# Overview of the SYSTDG Modeling

- SYSTDG Model based on HydSim daily modulated flows 70 year simulation
- Empirically based model of TDG Saturation
  - Developed to simulate TDG exchange of real-time project operations
  - Used for decision support of system TDG management

# Overview of the SYSTDG Modeling

- Geographic Domain
  - Columbia River from US Border to Bonneville Dam
  - Snake River from Anatone to confluence with CR
    - Dworshak and Clearwater River
  - Storage Project treated independently
    - Brownlee, Libby, Hungry Horse

# Overview of the SYSTDG Modeling

- Modeling Inputs
  - Daily modulated flows from HydSim
    - Alternatives evaluated RC-CC, 2A-TC, 2B-TC, 2A-TT
    - Components E1 and E2
  - Boundary Conditions
    - US/Canada – flow weighted average Keenleyside, Brilliant, Waneta
    - Small Tributary flows assumed TDG of 100%

# Overview of the SYSTDG Modeling

- Models outputs
  - Daily Average TDG in Forebay, Spill, and Tailwater
    - Tailwater TDG flow weighted average of project releases
    - Residual TDG level arriving at next downstream dam
- Assumptions
  - Temperature impacts were not considered
  - Extrapolation of TDG production model for high spillway flows

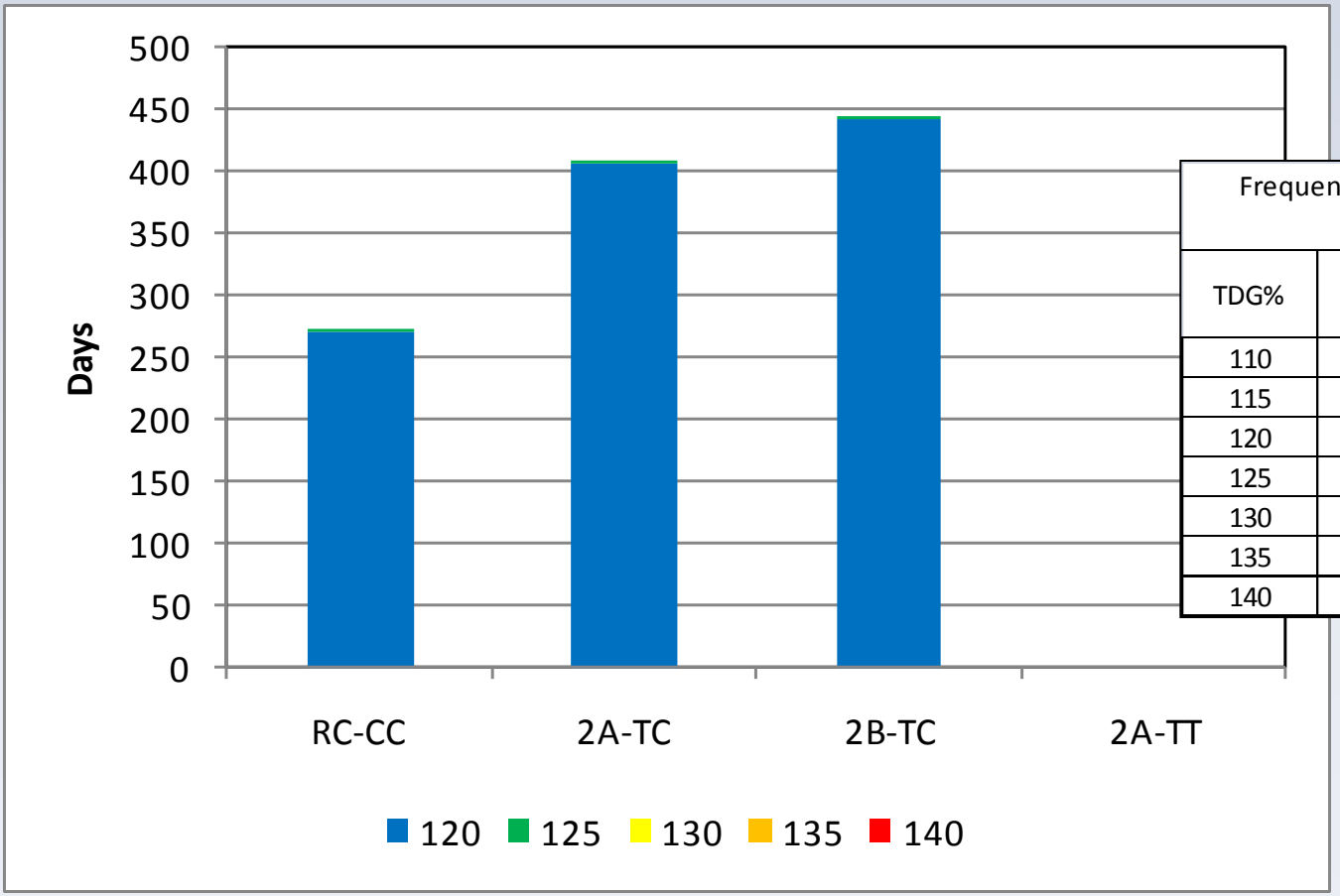
# Approach to TDG Assessment

- Segment Basin Regions
  - Canadian Projects & US/Canada Border
  - Headwater Projects (DWR, HGH, LIB, BRN)
  - Middle Columbia (GCL-PRD)
  - Lower Snake (LWG-IHR)
  - Lower Columbia (MCN-BON)

# Canadian Projects & US/Canada Border

- Summary of Alternatives at Brilliant & Waneta
  - *Spill Volumes unchanged*
  - *TDG loadings unchanged*
  - *Assuming Waneta powerhouse expansion complete*
- TDG summary for Columbia River at Keenleyside
  - *Spill volumes substantially less for 2A-TT*
  - *2A-TT produces substantially less TDG*
  - *2A-TC and 2B-TC result in the higher TDG levels*

# Summary of TDG at Keenleyside Dam Tailwater - Alternatives

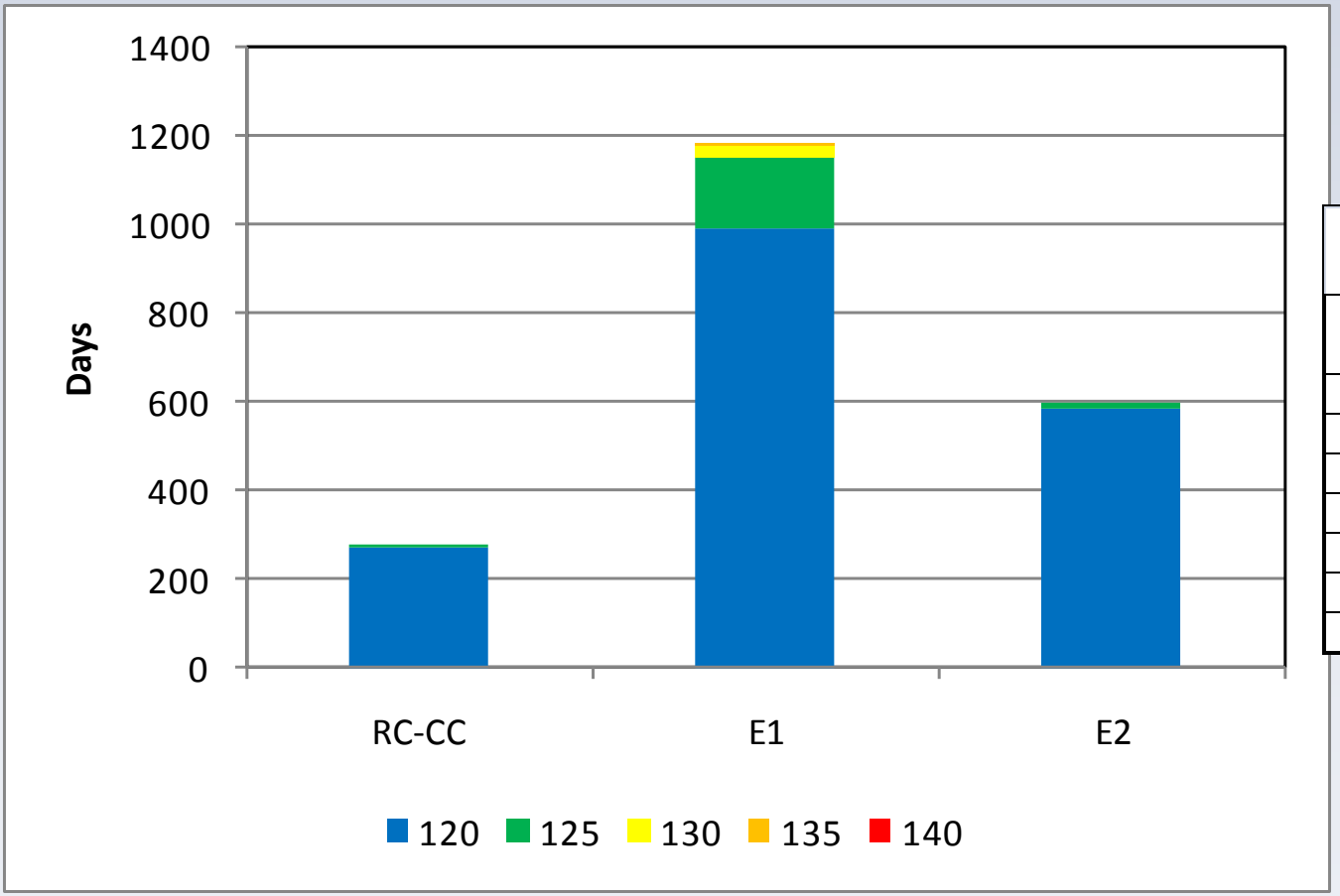



Number of Days Tailwater TDG levels was greater than 120% for Alternative 2A-TT was zero based on 70 year period of record (25550 days)

Frequency of Exceedance of TDG Saturation at Keenleyside Dam Tailwater

| TDG% | RC-CC (days) | 2A-TC (days) | 2B-TC (days) | 2A-TT (days) |
|---|---|---|---|---|
| 110 | 4866 | 6144 | 6306 | 2601 |
| 115 | 1487 | 1965 | 2159 | 607 |
| 120 | 273 | 410 | 445 | 0 |
| 125 | 3 | 3 | 3 | 0 |
| 130 | 0 | 0 | 0 | 0 |
| 135 | 0 | 0 | 0 | 0 |
| 140 | 0 | 0 | 0 | 0 |

# Summary of TDG at Keenleyside Dam Tailwater–Components E1, E2




Prominent increase in TDG saturation of 120% and higher for E1 and E2 compared to CC

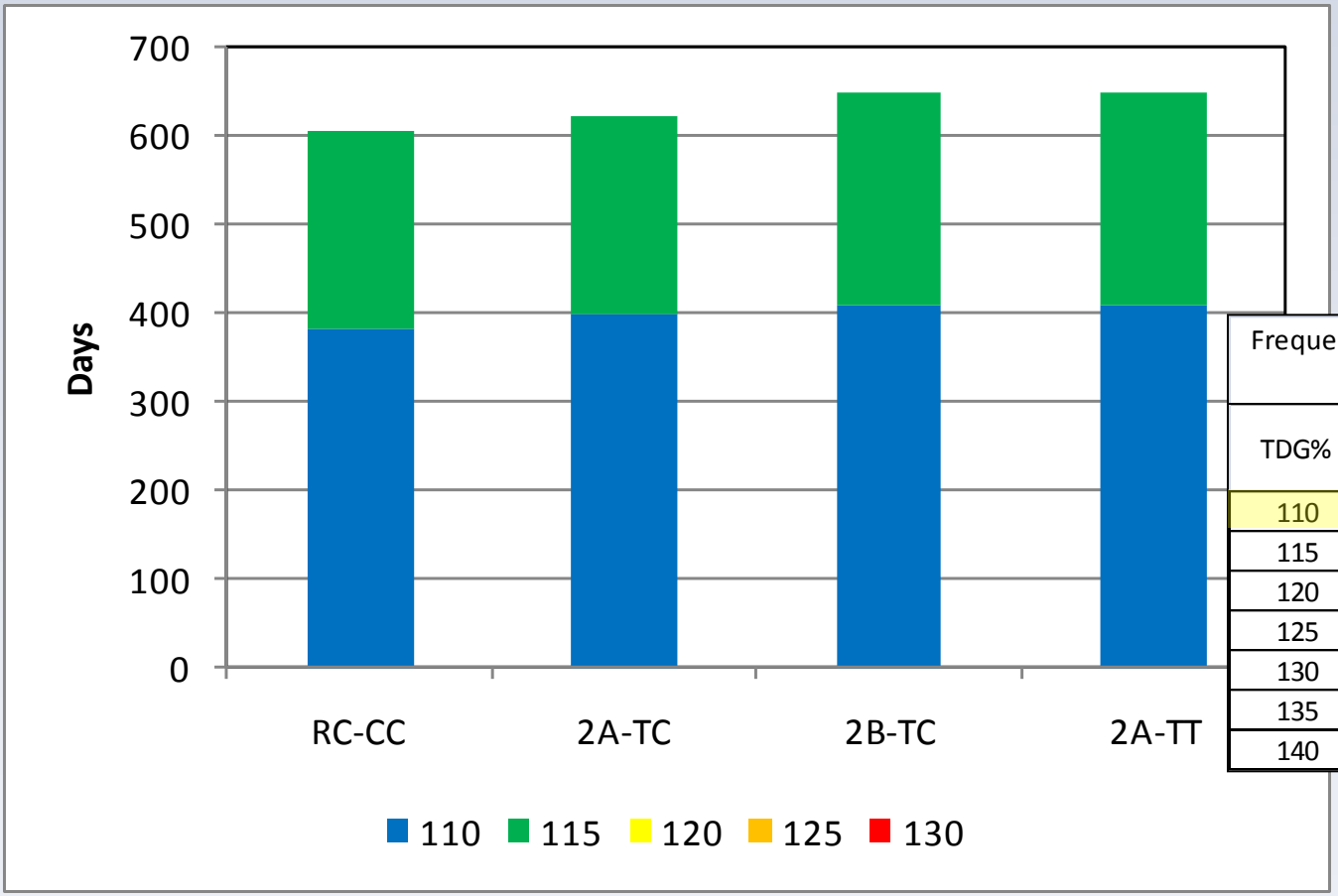
Frequency of Exceedance of TDG Saturation at Keenleyside Dam Tailwater

| TDG% | RC-CC (days) | E1 (days) | E2 (days) |
|---|---|---|---|
| 110 | 4866 | 7278 | 7402 |
| 115 | 1487 | 3671 | 2929 |
| 120 | 273 | 1183 | 596 |
| 125 | 3 | 190 | 9 |
| 130 | 0 | 30 | 0 |
| 135 | 0 | 4 | 0 |
| 140 | 0 | 0 | 0 |

# Headwater Projects

- Negligible TDG differences between Alternatives over study period for: Brownlee, Libby, Dworshak and Hungry Horse
  - No/minimal difference in refill/spill volumes from reservoir
  - No difference in TDG loadings
- E Components higher and lower TDG loading
  - E1 prominently higher TDG loading
  - E2 lower TDG loading at Libby Dam
    - Alternatives require spill for deeper draft of reservoir

# Summary of TDG at Libby Dam Tailwater, Alternatives

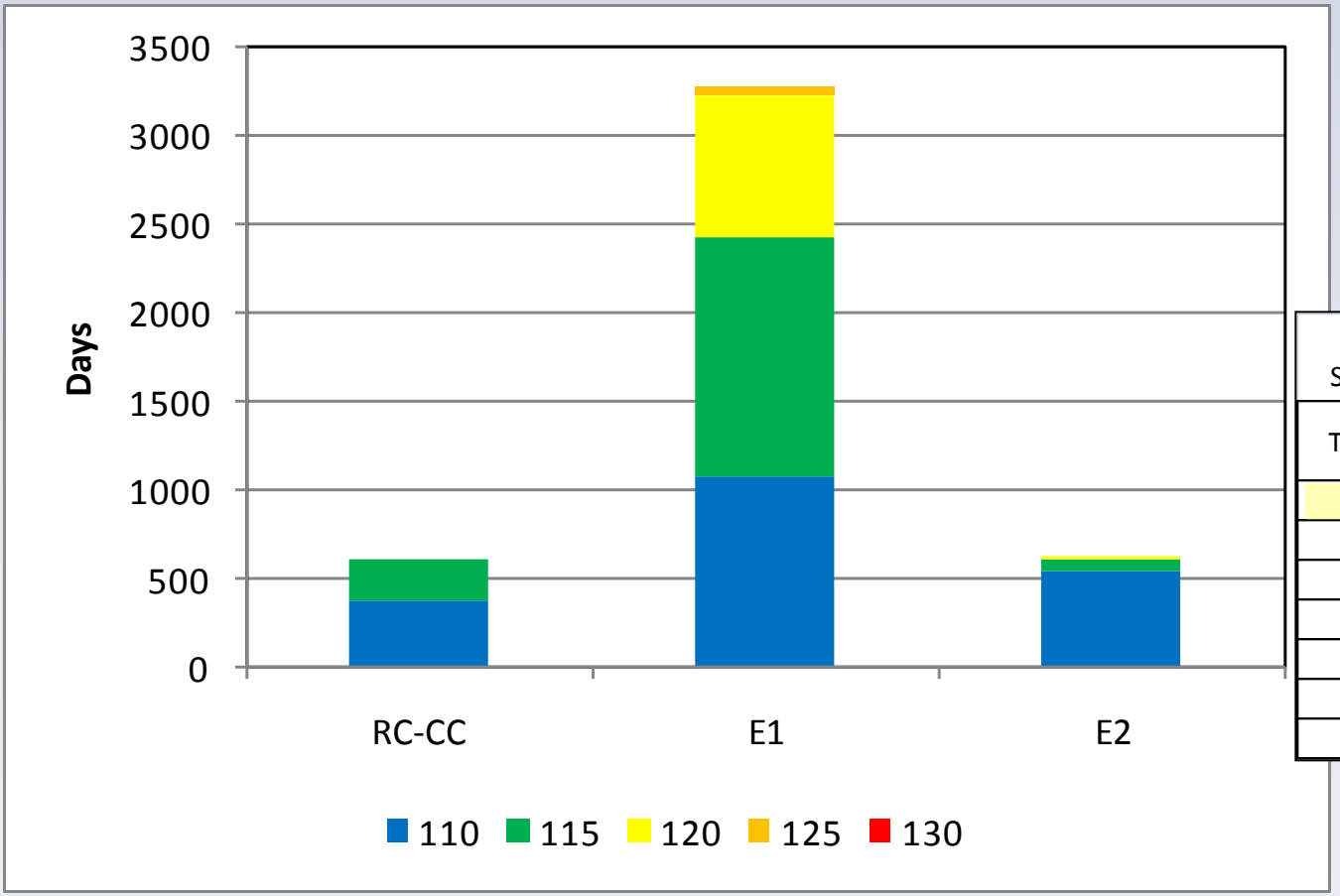



Number of days tailwater TDG levels exceeded 110% for Alternatives was nearly the same: 14 day difference for 2B-TC, 2A-TT compared to CC

Frequency of Exceedance of TDG Saturation at Libby Dam Tailwater

| TDG% | RC-CC (days) | 2A-TC (days) | 2B-TC (days) | 2A-TT (days) |
|---|---|---|---|---|
| 110 | 606 | 624 | 648 | 648 |
| 115 | 224 | 224 | 238 | 238 |
| 120 | 0 | 0 | 0 | 0 |
| 125 | 0 | 0 | 0 | 0 |
| 130 | 0 | 0 | 0 | 0 |
| 135 | 0 | 0 | 0 | 0 |
| 140 | 0 | 0 | 0 | 0 |

# Summary of TDG at Libby Dam Tailwater, Components E1, E2




All Alternative have same results at RC-CC
Note: TDG exceedance of 110% 5 times more frequent for E1 compared to CC

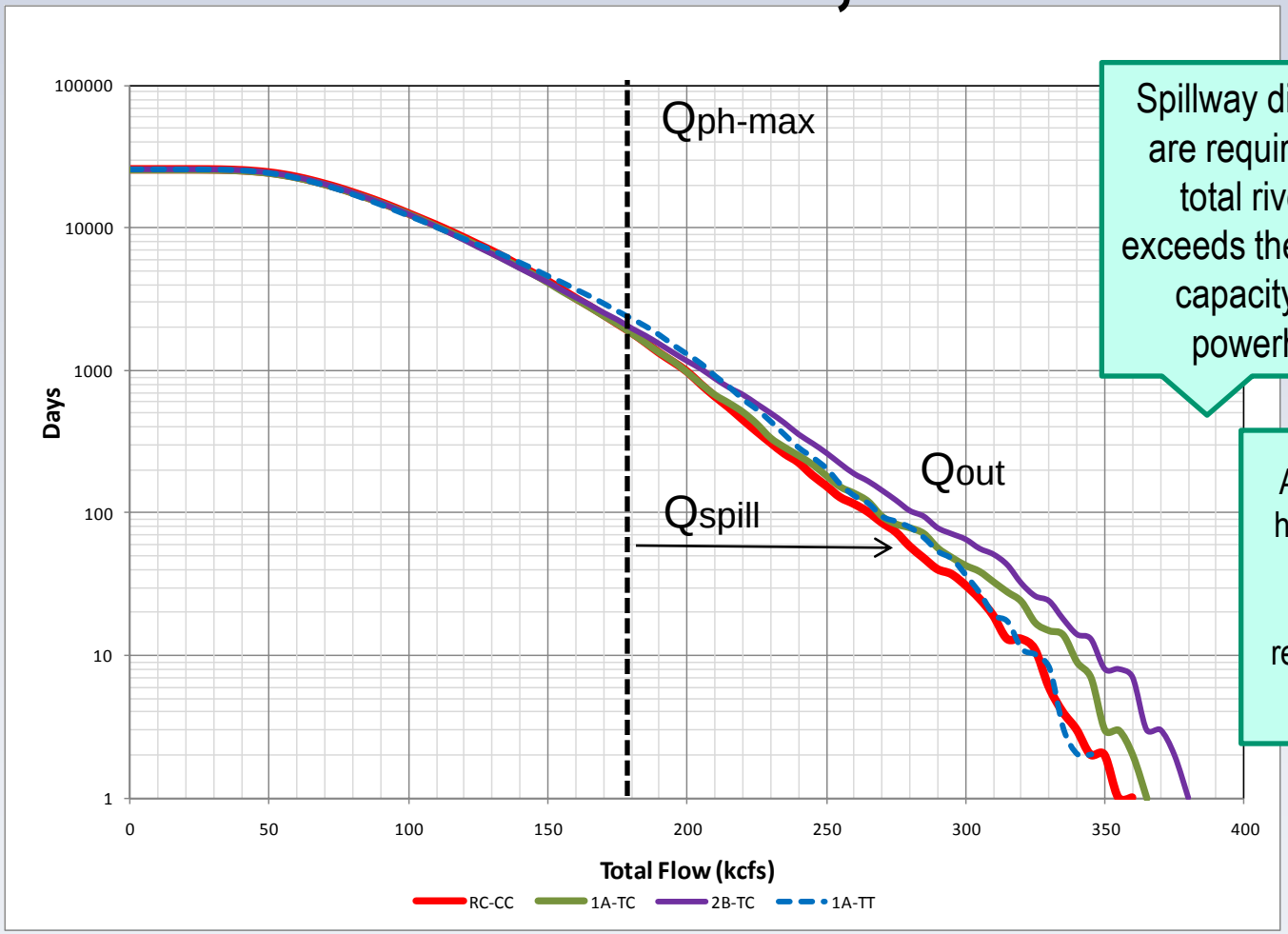
Frequency of Exceedance of TDG Saturation at Libby Dam Dam Tailwater

| TDG% | RC-CC (days) | E1 (days) | E2 (days) |
|---|---|---|---|
| 110 | 606 | 3275 | 612 |
| 115 | 224 | 2200 | 70 |
| 120 | 0 | 838 | 1 |
| 125 | 0 | 47 | 0 |
| 130 | 0 | 0 | 0 |
| 135 | 0 | 0 | 0 |
| 140 | 0 | 0 | 0 |

# Results Columbia River

- **Grand Coulee Dam - Critical Location**
  - Spill volumes smallest on CR (large hydraulic capacity)
  - Major TDG source when spilling due to:
    - Regulating Outlet (RO) produces extremely high TDG levels
    - Drum gates produce moderate TDG levels
  - Deeper draft increases likelihood of RO operations
    - 2A-TT Alternative frequently deep draft in high flow years
    - 2B-TC Alternative with shallower draft in high flow years

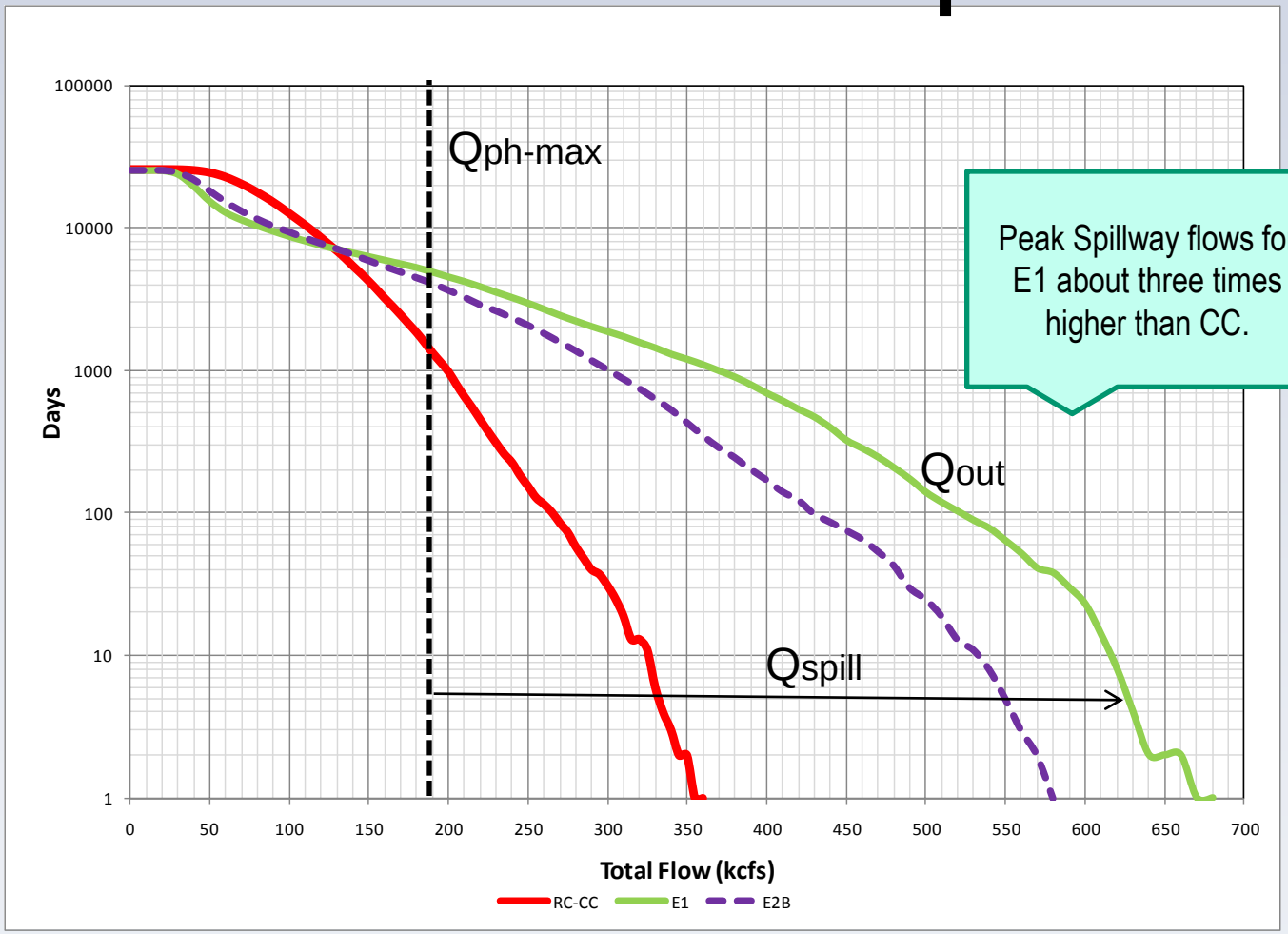
# Summary of Columbia River Total Flow at Grand Coulee Dam, Alternatives



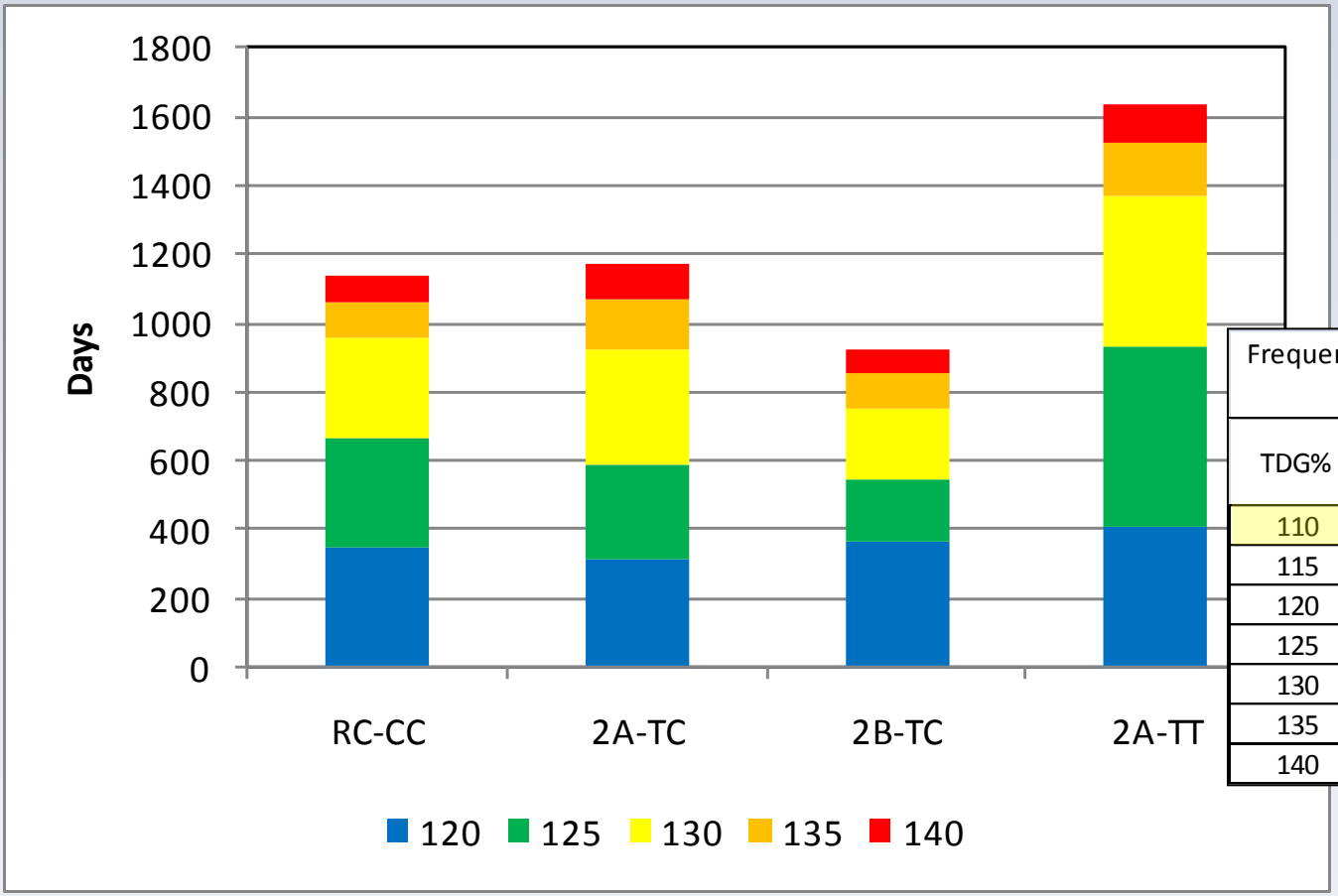

Spillway discharges are required when total river flow exceeds the hydraulic capacity of the powerhouse

Alternative 2B-TC has higher peak daily flows and larger spill rates
Note: This feature is retained throughout the CR to Bonneville

# Summary of Columbia River Total Flow at Grand Coulee Dam – Components E1, E2



# Summary of TDG at Grand Coulee Dam Tailwater, Alternatives



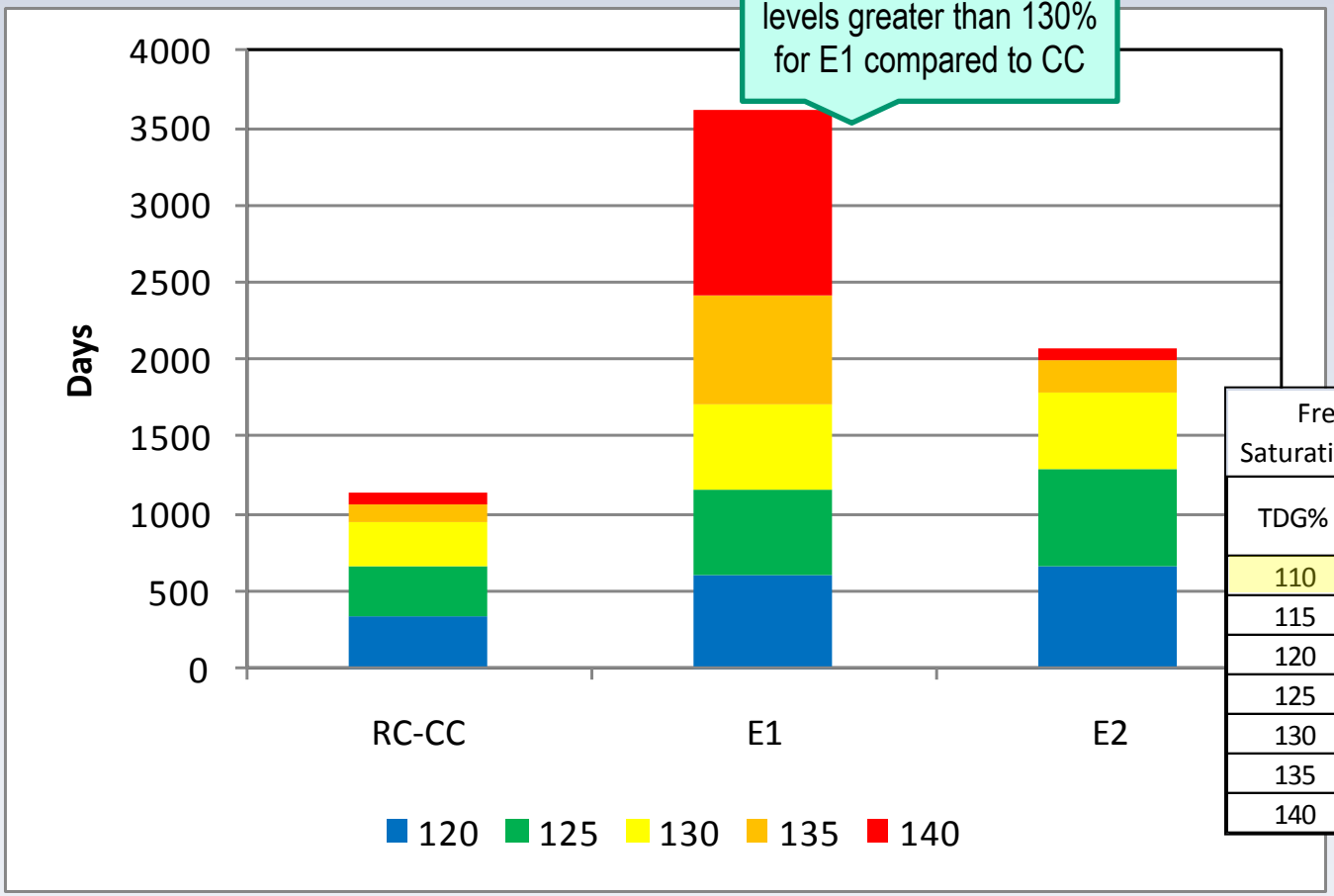

Alternative representation of Tailwater TDG Estimates showing 2A-TT with higher frequency of TDG levels greater than 120%

Frequency of Exceedance of TDG Saturation at Grand Coulee Dam Tailwater

| TDG% | RC-CC (days) | 2A-TC (days) | 2B-TC (days) | 2A-TT (days) |
|---|---|---|---|---|
| 110 | 4723 | 4865 | 4540 | 4422 |
| 115 | 1768 | 1798 | 1571 | 2287 |
| 120 | 1139 | 1168 | 924 | 1638 |
| 125 | 795 | 855 | 556 | 1230 |
| 130 | 472 | 579 | 381 | 705 |
| 135 | 185 | 241 | 171 | 273 |
| 140 | 81 | 98 | 73 | 110 |

# Summary of TDG at Grand Coulee Dam Tailwater, Components E1, E2

5 fold increase in TDG levels greater than 130% for E1 compared to CC




Both components result in prominently higher TDG loading from Grand Coulee Dam.

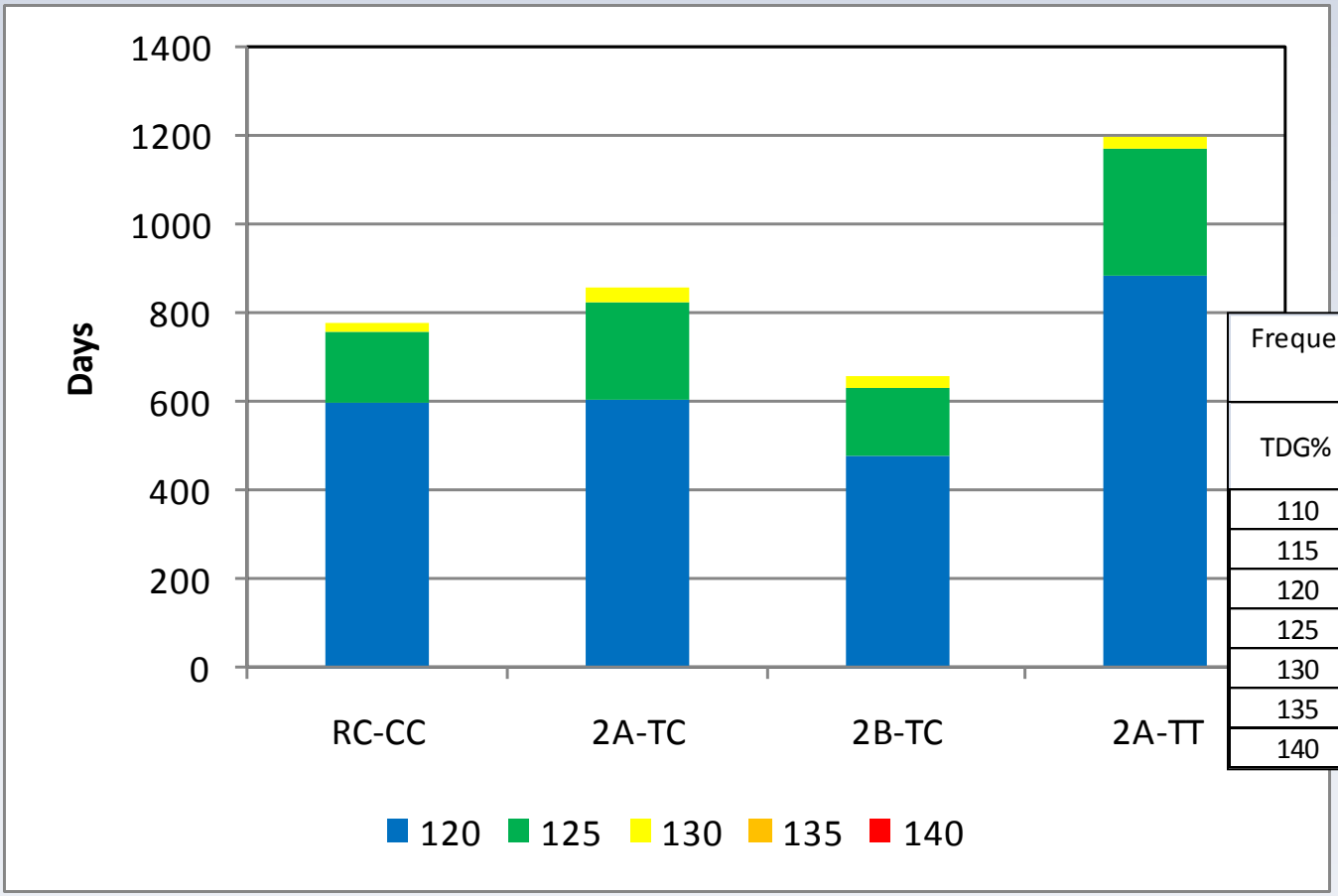
Frequency of Exceedance of TDG Saturation at Grand Coulee Dam Tailwater

| TDG% | RC-CC (days) | E1 (days) | E2 (days) |
|---|---|---|---|
| 110 | 4723 | 5545 | 5269 |
| 115 | 1768 | 4263 | 2772 |
| 120 | 1139 | 3609 | 2076 |
| 125 | 795 | 2999 | 1414 |
| 130 | 472 | 2457 | 795 |
| 135 | 185 | 1897 | 300 |
| 140 | 81 | 1195 | 78 |

# Middle Columbia

- **Chief Joseph Dam-Critical Location**
  - Spill volumes influenced both by flood flows and hydropower operations (lack of load-reserves)
  - Reduction in TDG levels when forebay TDG levels are high from GCL
  - Resultant TDG loading
    - Higher TDG levels for 2A-TT caused by upstream TDG sources
    - Lowering of peak tailwater TDG levels compared to forebay

# Summary of TDG at Chief Joseph Dam Tailwater, Alternatives

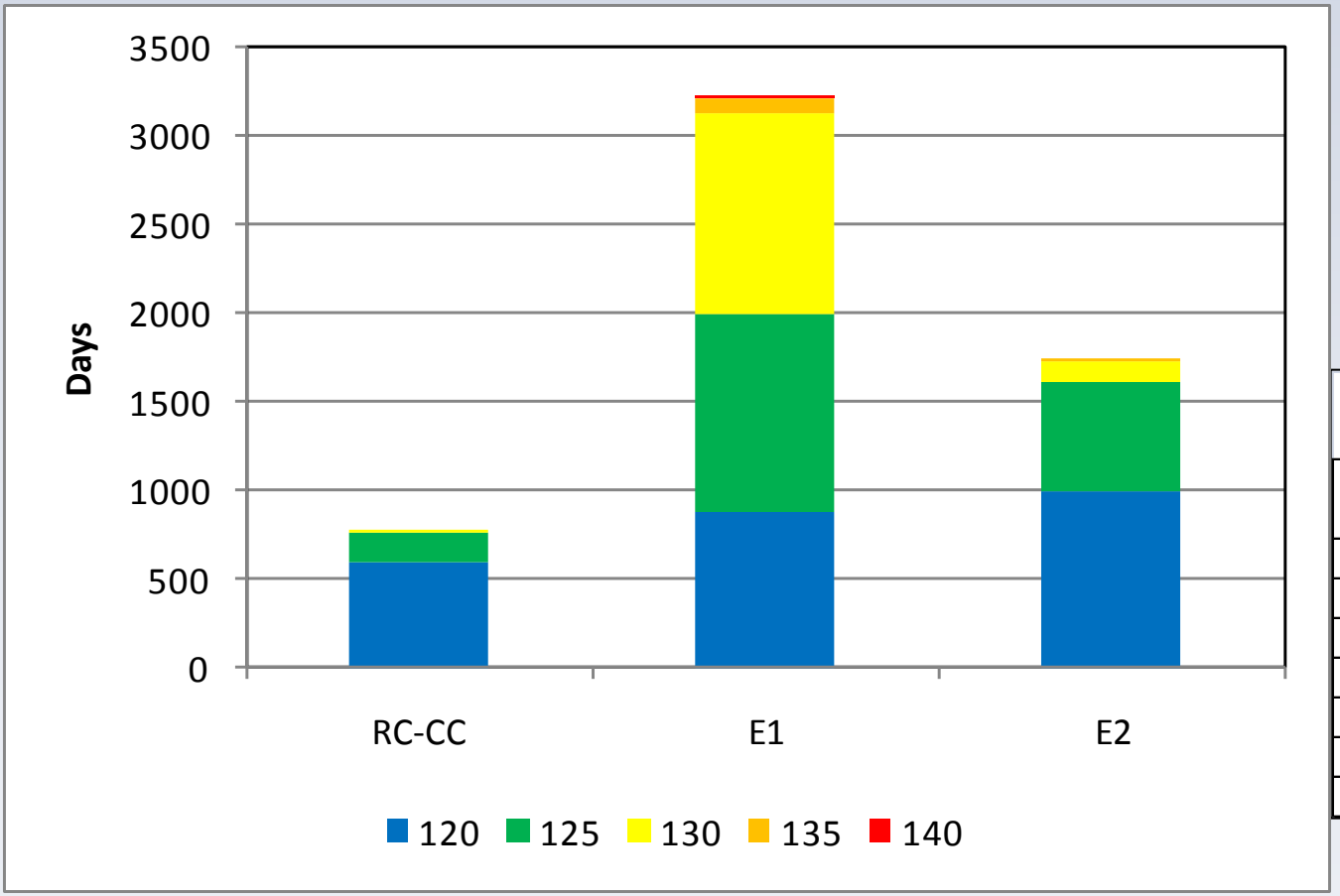



Note: Peak TDG levels are only 130% in CHJ tailwater compared with 136% in forebay. Spillway release are lowering the TDG levels in the Columbia River when high forebay conditions are present

Frequency of Exceedance of TDG Saturation at Chief Joseph Dam Tailwater

| TDG% | RC-CC (days) | 2A-TC (days) | 2B-TC (days) | 2A-TT (days) |
|---|---|---|---|---|
| 110 | 3468 | 3695 | 3384 | 3751 |
| 115 | 1728 | 1765 | 1814 | 2396 |
| 120 | 775 | 856 | 655 | 1197 |
| 125 | 178 | 252 | 176 | 314 |
| 130 | 20 | 28 | 22 | 27 |
| 135 | 0 | 0 | 0 | 0 |
| 140 | 0 | 0 | 0 | 0 |

# Summary of TDG at Chief Joseph Dam Tailwater, Components E1, E2




Duration of TDG greater than of 120% was increased for E1 four fold when compared to CC. Prominent contribution of high TDG loading from upstream TDG sources

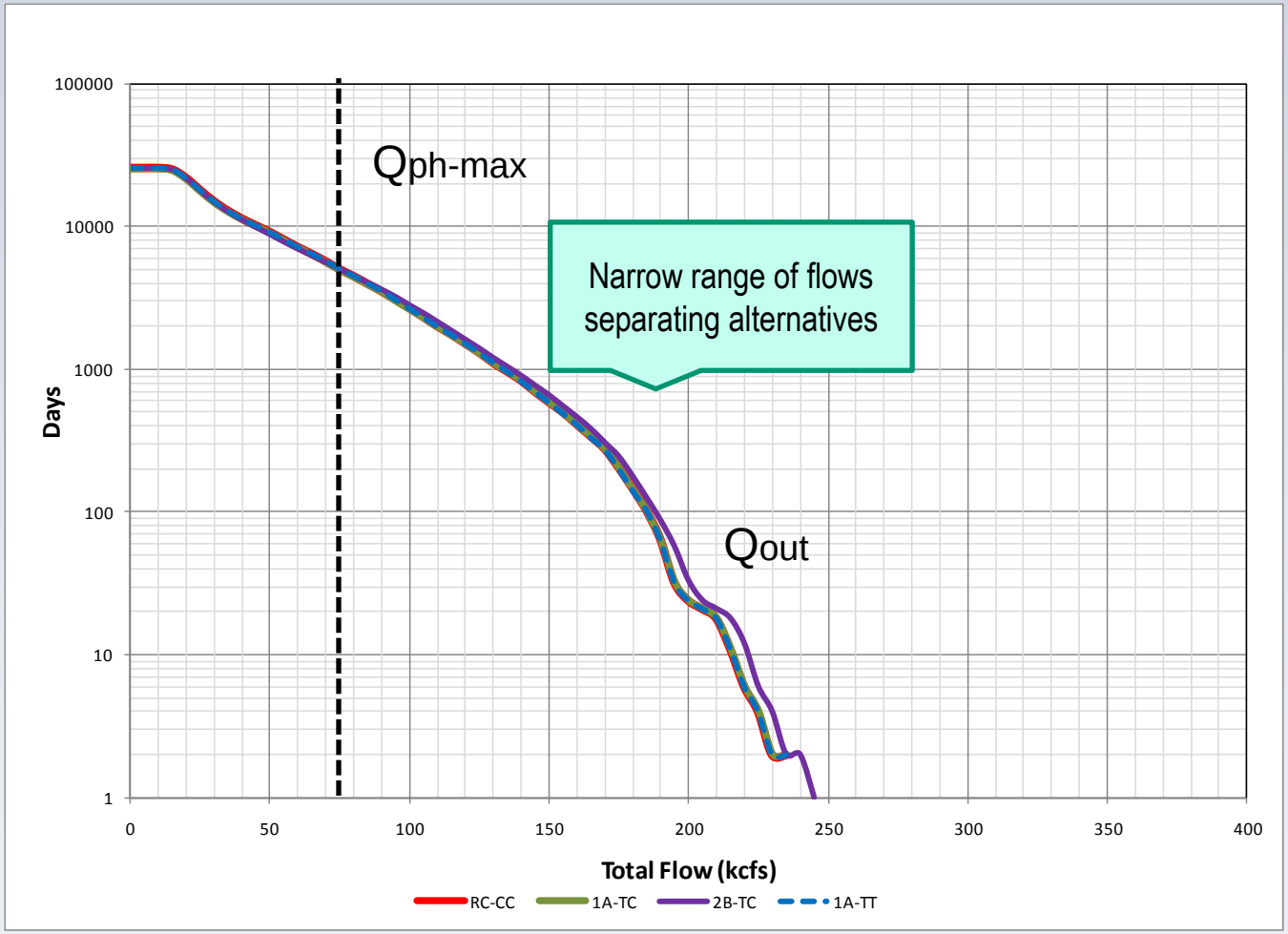
Frequency of Exceedance of TDG Saturation at Chief Joseph Dam Tailwater

| TDG% | RC-CC (days) | E1 (days) | E2 (days) |
|---|---|---|---|
| 110 | 3468 | 5092 | 4268 |
| 115 | 1728 | 4133 | 2674 |
| 120 | 775 | 3224 | 1746 |
| 125 | 178 | 2347 | 750 |
| 130 | 20 | 1225 | 129 |
| 135 | 0 | 90 | 10 |
| 140 | 0 | 3 | 0 |

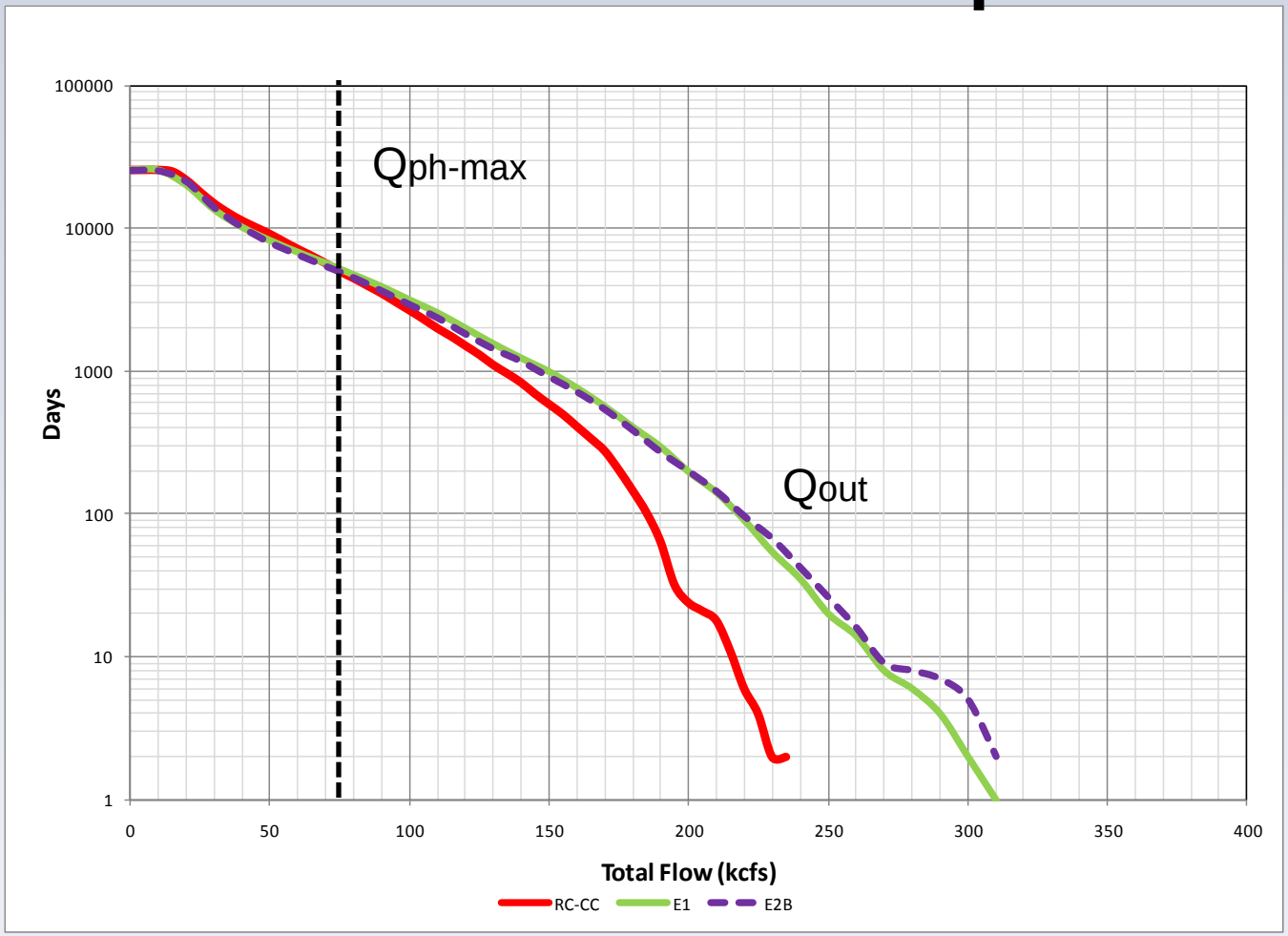
# Snake River-IHR TDG Assessment

- **Ice Harbor**
  - Largest spill volume on the Snake River
  - Lower TDG producer allowing high rates of spill without exceeding 120% saturation
  - Hydropower operations prominent cause of spill volume differences between alternatives
    - 2B-TC resulted in highest spill volumes and TDG loading

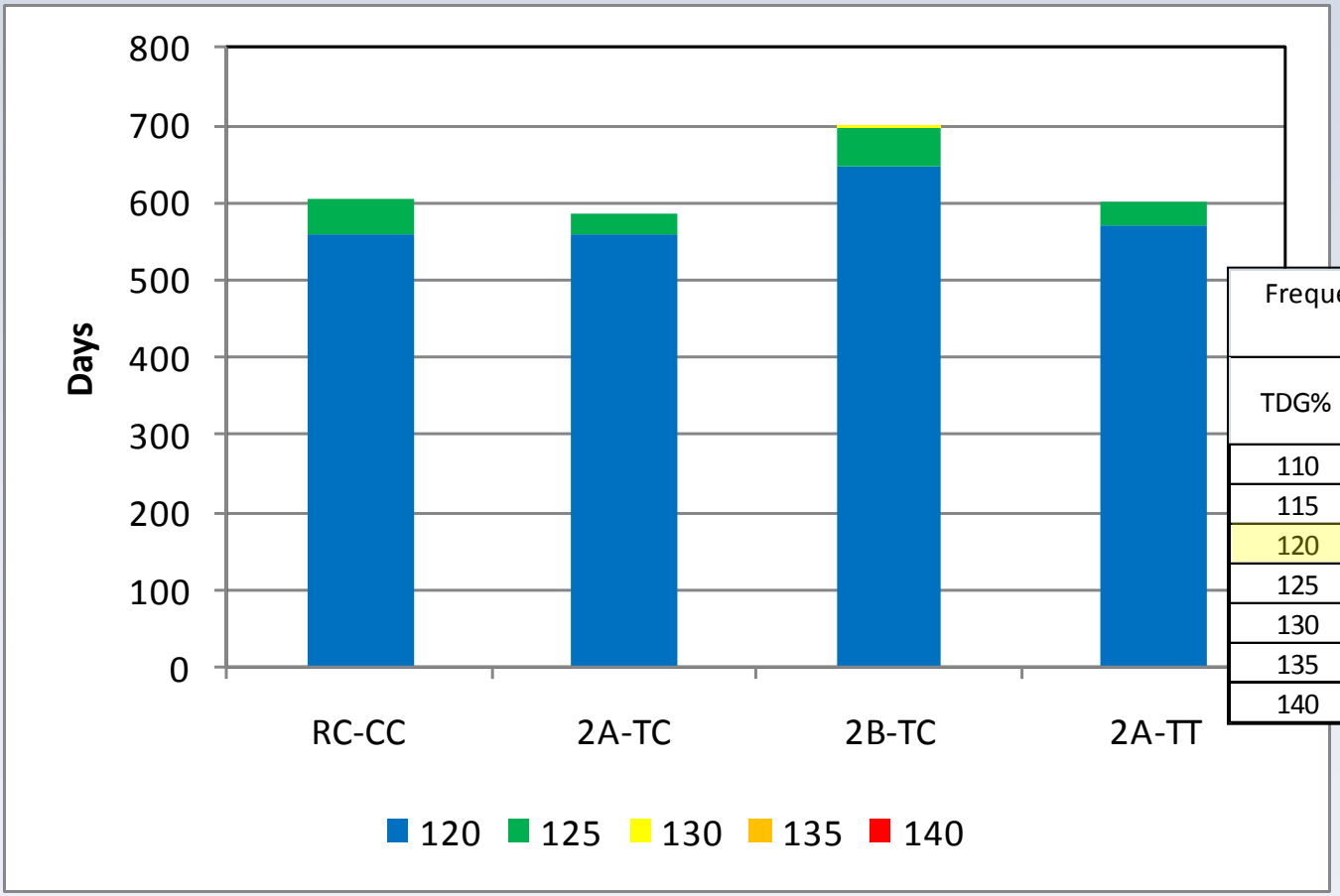
# Summary of Snake River Total Flow at Ice Harbor Dam - Alternatives



# Summary of Snake River Total Flow at Ice Harbor Dam - Components



# Summary of TDG at Ice Harbor Dam Tailwater, Alternatives

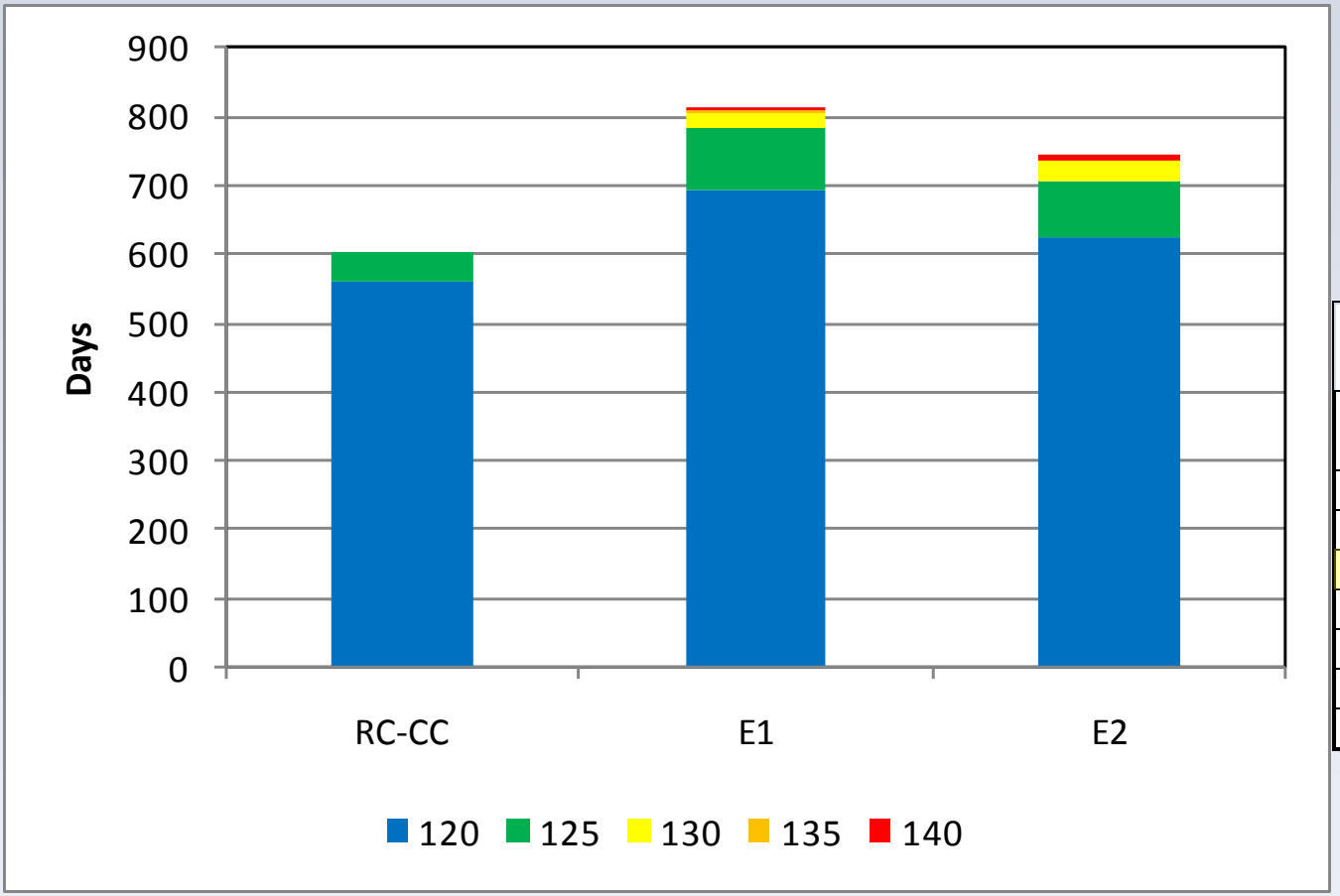



Tailwater TDG threshold of 120% slightly higher TDG levels for 2B-TC

Frequency of Exceedance of TDG Saturation at Ice Harbor Dam Tailwater

| TDG% | RC-CC (days) | 2A-TC (days) | 2B-TC (days) | 2A-TT (days) |
|---|---|---|---|---|
| 110 | 8926 | 8931 | 8874 | 8934 |
| 115 | 2695 | 2621 | 2807 | 2903 |
| 120 | 604 | 585 | 698 | 602 |
| 125 | 44 | 27 | 52 | 31 |
| 130 | 0 | 0 | 2 | 0 |
| 135 | 0 | 0 | 0 | 0 |
| 140 | 0 | 0 | 0 | 0 |

# Summary of TDG at Ice Harbor Dam Tailwater, Components E1, E2




Component E1 had the highest number of days with TDG greater than 120% .TDG levels over 140% for E1 and E2

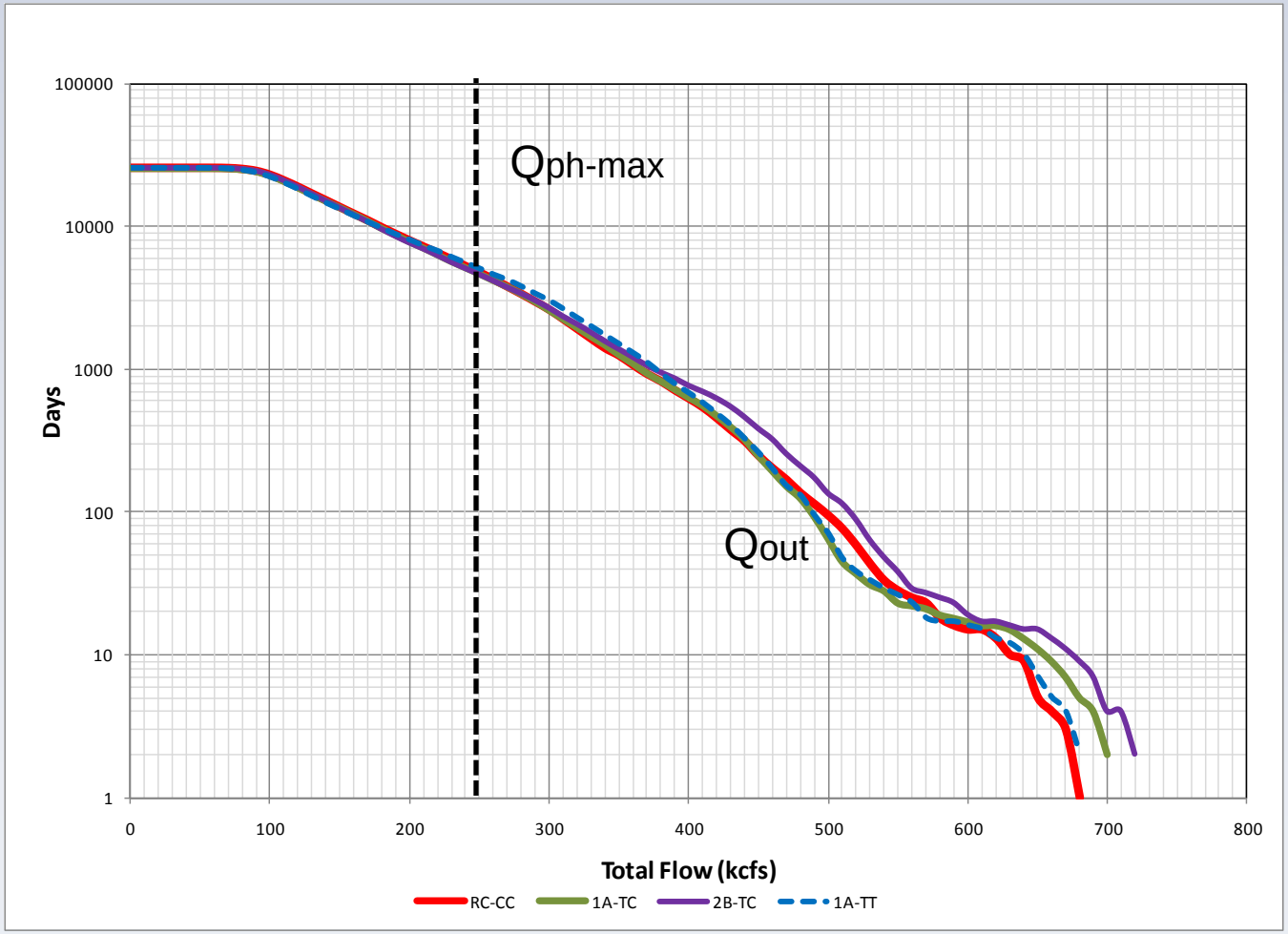
Frequency of Exceedance of TDG Saturation at Ice Harbor Dam Tailwater

| TDG% | RC-CC (days) | E1 (days) | E2 (days) |
|---|---|---|---|
| 110 | 8926 | 12076 | 12094 |
| 115 | 2695 | 4947 | 4715 |
| 120 | 604 | 813 | 743 |
| 125 | 44 | 119 | 120 |
| 130 | 0 | 29 | 35 |
| 135 | 0 | 10 | 9 |
| 140 | 0 | 2 | 5 |

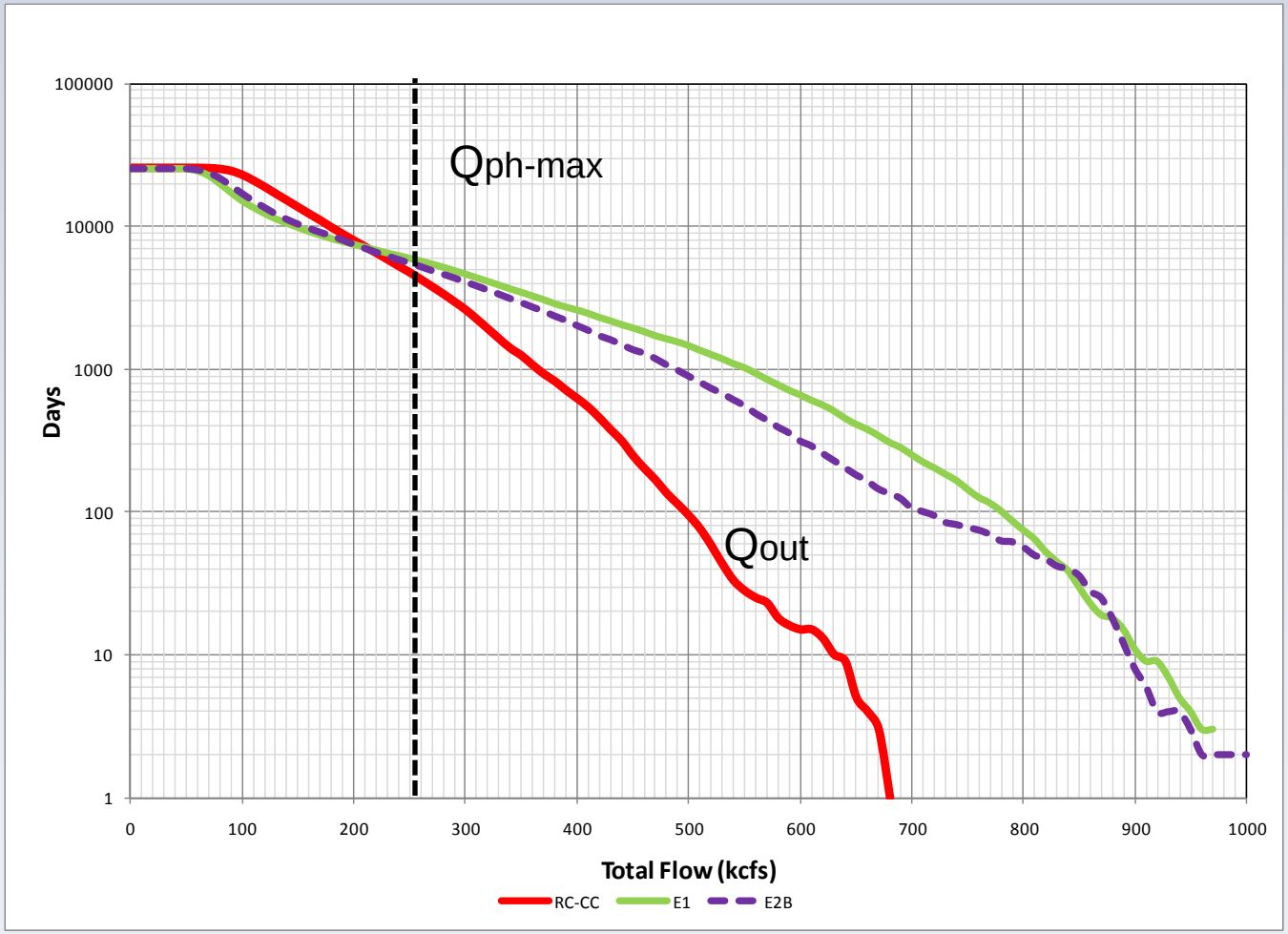
# Lower Columbia-TDA

- The Dalles Dam – Critical Location
  - Large hydraulic capacity of powerhouse
  - TDG response curve weakly related to spill discharge
    - Ratio of $\Delta$TDG to $\Delta$Q is small (TDG generation is not highly sensitive to spill)
    - High priority for TDG management operations

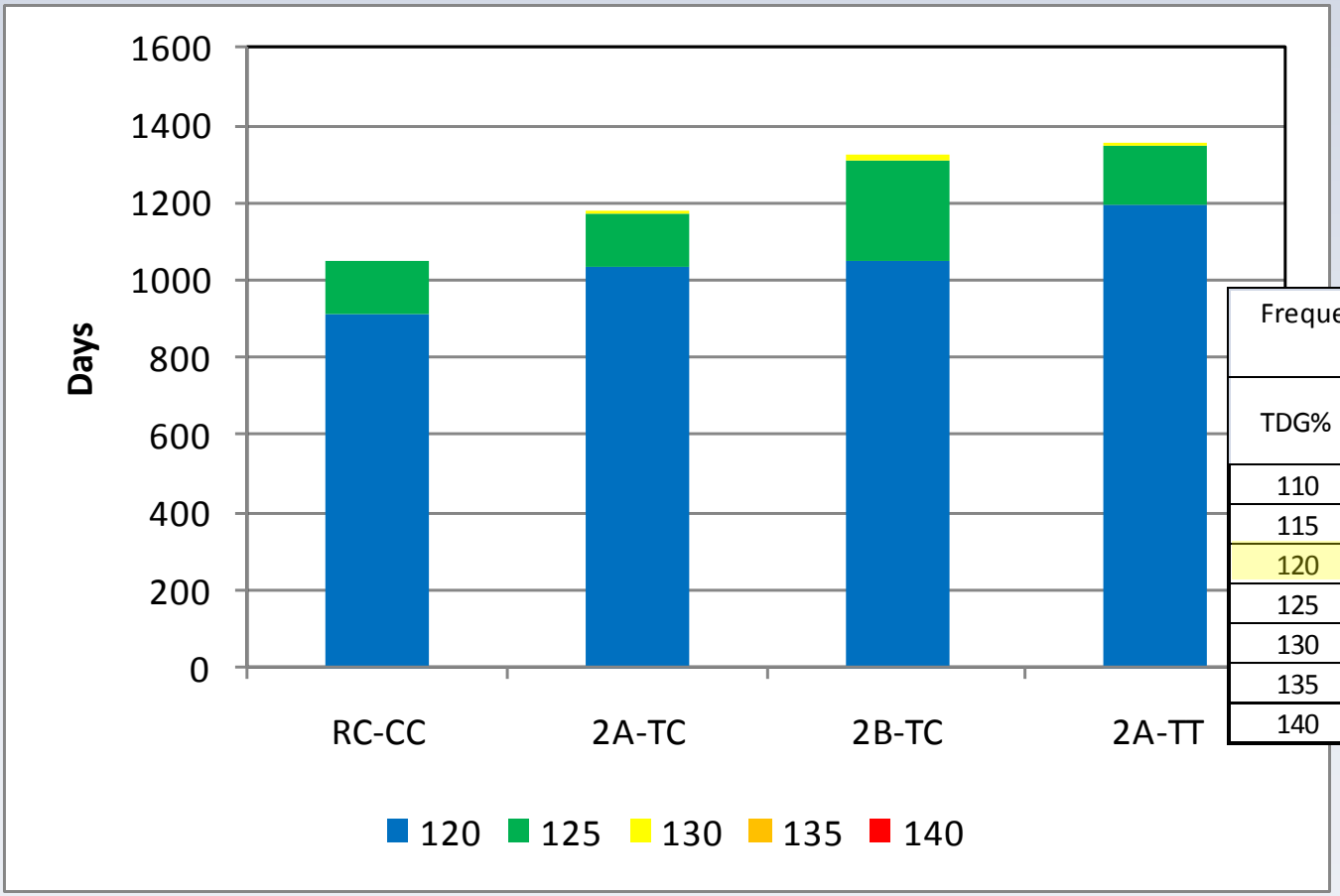
# Summary of Columbia River Total Flow at The Dalles Dam



# Summary of Columbia River Total Flow at The Dalles Dam



# Summary of TDG at The Dalles Dam Tailwater, Alternatives

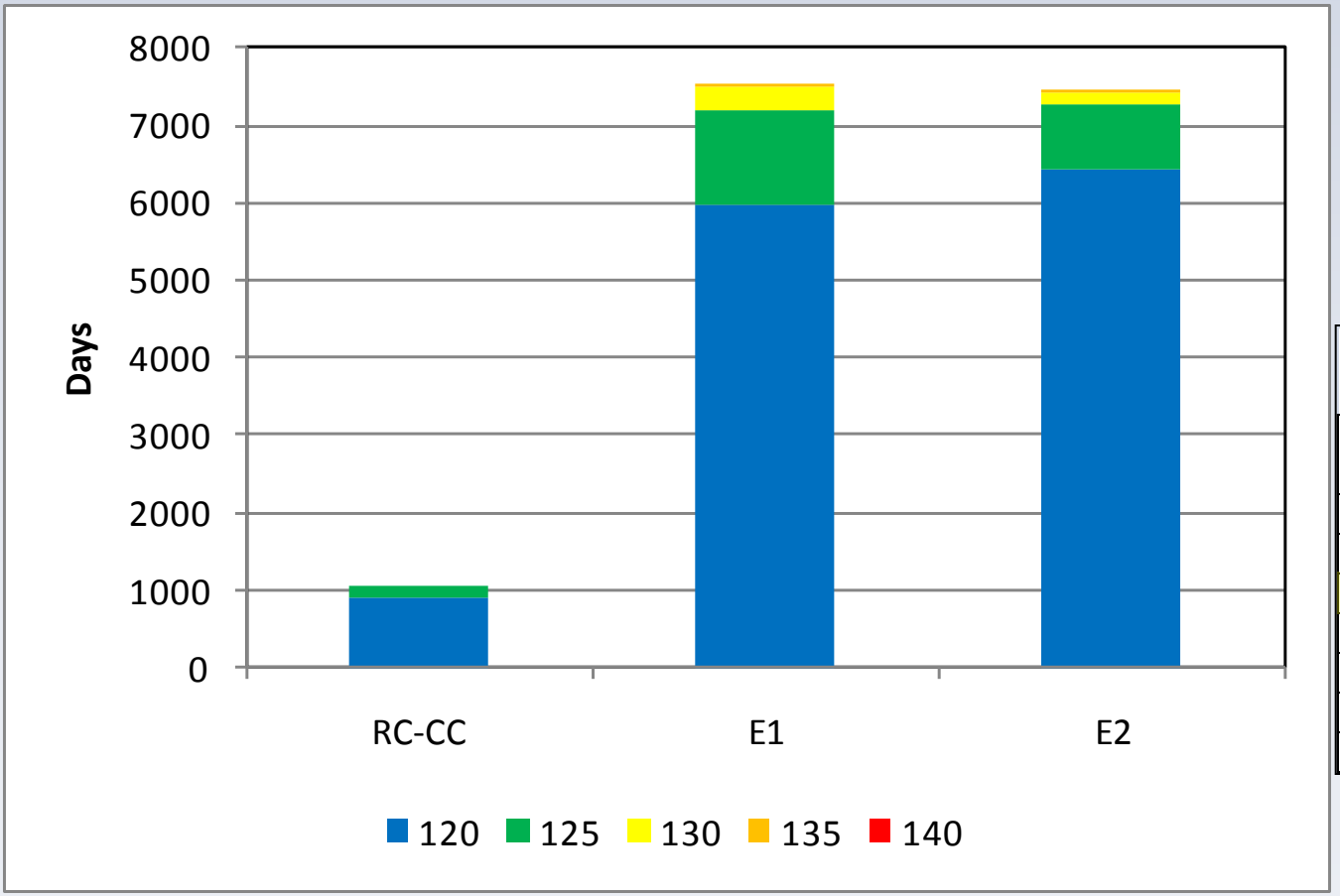



Number of days tailwater TDG was greater than 120% was higher for 2B-TC and 2A-TT by about 28% compared to CC

Frequency of Exceedance of TDG Saturation at The Dalles Dam Tailwater

| TDG% | RC-CC (days) | 2A-TC (days) | 2B-TC (days) | 2A-TT (days) |
|---|---|---|---|---|
| 110 | 10573 | 10635 | 10460 | 10710 |
| 115 | 6194 | 6254 | 6224 | 6278 |
| 120 | 1049 | 1176 | 1321 | 1349 |
| 125 | 136 | 143 | 275 | 158 |
| 130 | 0 | 6 | 11 | 4 |
| 135 | 0 | 0 | 0 | 0 |
| 140 | 0 | 0 | 0 | 0 |

# Summary of TDG at The Dalles Dam Tailwater, Components E1, E2



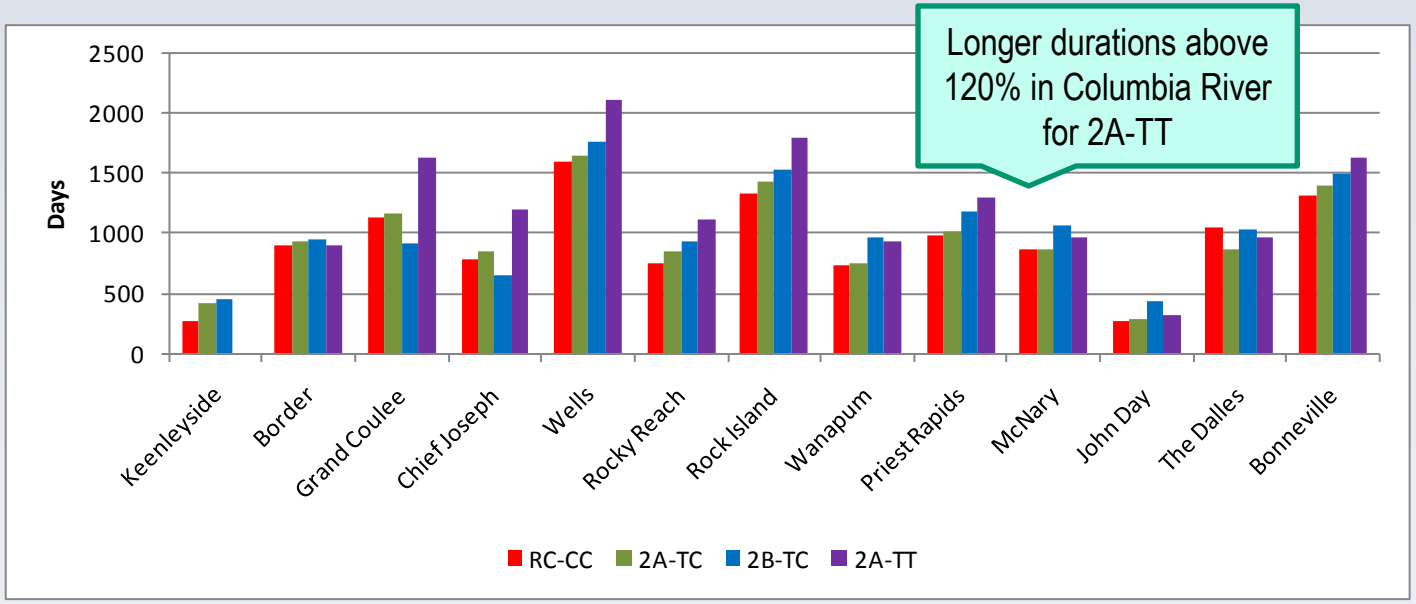

The increase in the number of day where TDG was greater than 120% was higher for E1 and E2 by about 700% compared to CC

Frequency of Exceedance of TDG Saturation at The Dalles Dam Tailwater

| TDG% | RC-CC (days) | E1 (days) | E2 (days) |
|---|---|---|---|
| 110 | 10573 | 12869 | 12867 |
| 115 | 6194 | 10621 | 10662 |
| 120 | 1049 | 7516 | 7410 |
| 125 | 136 | 1560 | 994 |
| 130 | 0 | 328 | 141 |
| 135 | 0 | 9 | 5 |
| 140 | 0 | 0 | 0 |

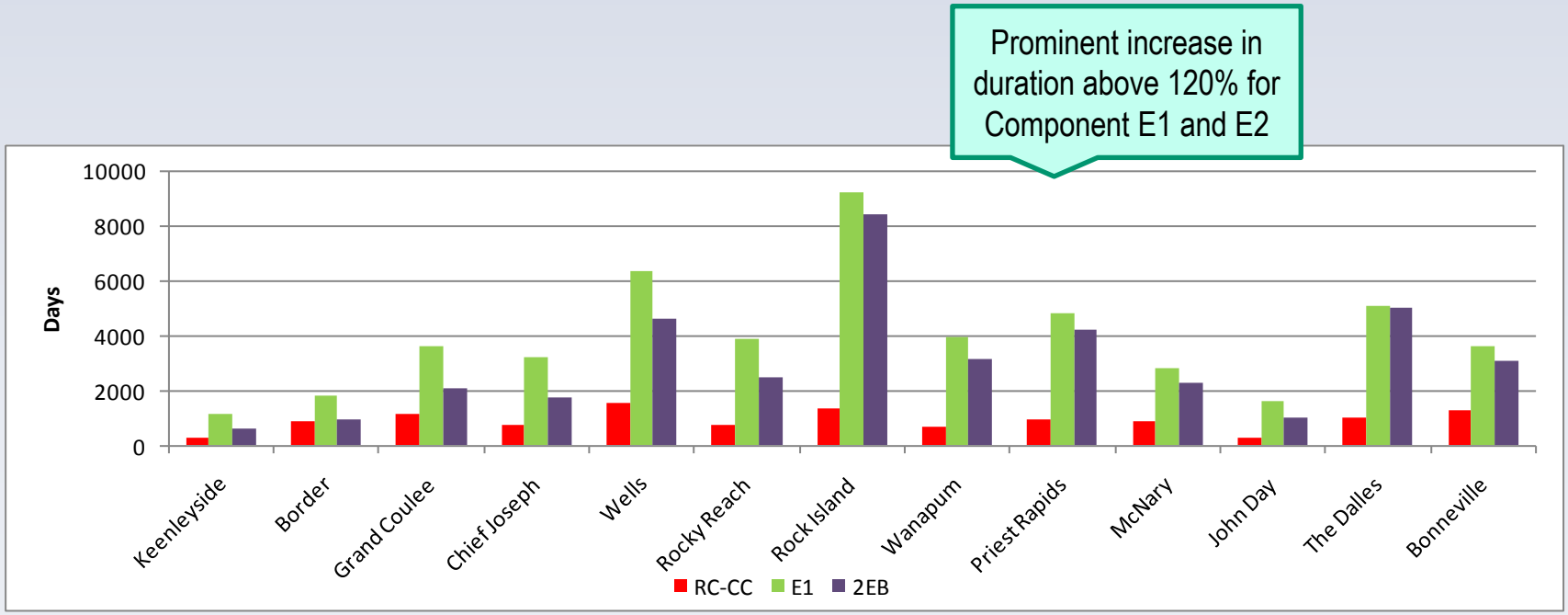
# Duration in days of tailwater TDG Saturation greater than 120% by project, Alternatives

| Duration in Days in the Project Tailwater where the TDG Saturatoin was greater than 120%, (70 year summary) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HKS | US/Can | GCL | CHJ | WEL | RRH | RIS | WAN | PRD | Mcn | JDA | TDA | BON |
| RR-CC | 273 | 892 | 1139 | 775 | 1593 | 749 | 1340 | 725 | 989 | 873 | 275 | 1049 | 1312 |
| 2A-TC | 410 | 931 | 1168 | 856 | 1649 | 843 | 1429 | 752 | 1015 | 861 | 282 | 868 | 1401 |
| 2B-TC | 445 | 943 | 924 | 655 | 1760 | 927 | 1536 | 962 | 1174 | 1058 | 430 | 1029 | 1503 |
| 2A-TT | 0 | 895 | 1638 | 1197 | 2115 | 1122 | 1799 | 926 | 1301 | 968 | 313 | 972 | 1633 |



# Duration in days of tailwater TDG Saturation greater than 120% by project, Components E1, E2

| Duration in Days in the Project Tailwater where the TDG Saturatoin was greater than 120%, (70 year summary) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HKS | US/Can | GCL | CHJ | WEL | RRH | RIS | WAN | PRD | Mcn | JDA | TDA | BON |
| RR-CC | 273 | 892 | 1139 | 775 | 1593 | 749 | 1340 | 725 | 989 | 873 | 275 | 1049 | 1312 |
| E1 | 1183 | 1821 | 3609 | 3224 | 6398 | 3901 | 9272 | 4002 | 4857 | 2852 | 1609 | 5094 | 3638 |
| E2B | 596 | 975 | 2076 | 1746 | 4660 | 2515 | 8472 | 3162 | 4248 | 2284 | 1057 | 5059 | 3090 |



# Summary of TDG Evaluation

- TDG evaluation of Alternatives and Components E1 and E2 Operations based on 70 year simulations using HydSim daily modulated flows with SYSTDG model
  - Reduction in TDG loading at Keenleyside Dam for 2A-TT
  - Increase in TDG loading at Grand Coulee Dam for 2A-TT
  - Chief Joseph has moderating impact on TDG loading when forebay TDG levels exceed 120%
  - Higher TDG loading in Lower CR for the 2B-TC alternative

# Summary of TDG Evaluation

- Headwater Projects minimal change in TDG loading for Alternatives
- Differences in TDG loading in Snake River for alternatives were small
- E1 and E2 Components resulted in prominent increases in tailwater TDG loading throughout the entire study area
  - 2 to 7 times more days above 120% for E1 compared to CC for Columbia River Dams